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European Assessment Document for

High-strength structural bolting assemblies for hydraulically operated, friction-less and torsion- free tightening



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This European Assessment Document (EAD) has been developed taking into account up-to-date technical and scientific knowledge at the time of issue and is published in accordance with the relevant provisions of Regulation (EU) 305/2011 as a basis for the preparation and issuing of European Technical Assessments (ETA).

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1 SCOPE OF THE EAD

1.1 Description of the construction product

This EAD covers high-strength structural bolting assemblies for hydraulically operated, friction-less and torsion-free tightening (in the following referred to as “high-strength structural bolting assemblies”). They are used to connect structural steel components.

The high-strength structural bolting assemblies consist of a stretch bolt (hexagon bolt) or a stud bolt with a round nut on the preload application side (see Annex A). On the opposite side round nuts are used. Annex B shows the various possible combinations. The surface protection consists either of a zinc flake coating or, alternatively, of a hot-dip galvanised or sherardised finish.

This EAD covers nominal bolt diameters greater or equal M 20 up to M 100 and a clamping length ratio of $k/d > 2,5$ (see Annex B; d = nominal thread diameter of the bolt).

The round nuts shown in Annex B are intended for use on the preload application side (see Annex B, blue coloured) and are designed so that the washer is integrated with the round nut. The use of additional washers on the preload application side is not intended.

The high-strength structural bolting assemblies do not contain more than 1,0 % by weight or volume (whichever is the more onerous) of homogeneously distributed organic material.

The high-strength structural bolting assemblies are not fully covered by the harmonised standard EN 14399-1¹ and the other non-harmonised parts of the EN 14399 series to which EN 14399-1 refers to. The high-strength structural bolting assemblies for hydraulically operated, frictionless and torsion-free preloading described in this EAD are not comparable with the construction products covered by this harmonised European standard. Unlike EN 14399-1 the pre-tensioning of the bolt is not achieved by tightening the nut but by hydraulic pre-tensioning system which ensures stress loads only in one direction (pure tension while systems covered by EN 14399-1 result in three directional stress distribution). The function of nuts is also different from those used in line with EN 14399-1 as nuts covered by the EAD just ensure that hydraulically set pre-tension is kept constant. The main differences are:

1. Different design principle

- The EN 14399 standard series cover only bolting assemblies where preloading is achieved by torque-controlled or combined tightening methods (torque methods). Thus, the bolts are subject to torsional stresses.
- In contrast, the products covered by this EAD are preloaded by means of a hydraulic bolt tensioning cylinder (BTC, not part of the product) which axially stretches the bolt so that the nuts can be turned to the final position without introducing torsional stresses into the bolts. Such a method is not foreseen in EN 14399-1.

2. Geometrical characteristics and size range

- The products comprise nominal diameters from M20 up to M100 with clamping length ratios greater than $2,5 \cdot d$.
- EN 14399-1 is essentially limited to hexagon bolts and associated nuts and washers with diameters up to M39.
- Special product forms such as stud-stretch bolts, round nuts with integrated bearing surfaces and their possible combinations are not included in any harmonised standard.

3. Different failure mechanism evolving from 1. and 2.

- Conventional high-strength structural bolting assemblies in accordance with EN 14399-1 generally fail by shear of the nut thread or by failure in the head-to-shank transition zone.

¹ All undated references to standards in this EAD are to be understood as references to the dated versions listed in chapter 4.

- The assemblies described in this EAD are designed in such a way that, under extreme loading, fracture occurs in the free threaded section under tension. This represents a different failure mechanism not addressed in the harmonised standard.

4. Lack of normative provisions for testing and assessment

- Essential performance aspects such as the fatigue behaviour of the bolt thread, the suitability for hydraulic preloading or the performance of round nuts with integrated washers are not covered by EN 14399-1.
- Therefore, the required product characteristics cannot be determined according to the test methods specified in EN 14399-1 and the related other parts of this standard series. Furthermore, product characteristics required in EN 14399-1, such as slip factors and friction coefficients (K-classes), are not relevant for these assemblies, since the preloading is achieved without torsional loading or frictional resistance.

5. Specific field of application

The bolting assemblies are intended for heavily loaded steel structures, where very high and precisely defined preloads, reproducible tightening conditions and large diameters are required.

Torsional parts and coefficients of friction (K classes) are not taken into account when considering the bolted connection.

In conclusion, the deviations described under 1–5 do not only concern product geometry or application range, but result in the incompatibility of the assessment and AVCP procedures defined in EN 14399-1 in connection with other parts of this standard series as referred to below.

The following essential characteristics and related test methods of the EN 14399 series are not relevant for hydraulically preloaded assemblies, since they are based on torque-controlled tightening and frictional behaviour, which are irrelevant under torsion-free hydraulic preloading:

- Friction coefficients / K-class verification (EN 14399-2, Annex G),
- Suitability tests for preloading by torque (EN 14399-2, EN 14399-4, EN 14399-7),
- Slip factor testing of connections (EN 1090-2 in conjunction with EN 14399),
- Tests of repeated tightening behaviour,
- Assessment of preload scatter due to torque method,
- Washer performance tests (EN 14399-5 / EN 14399-6).

Instead, this EAD introduces essential characteristics specifically adapted to hydraulic preloading, in particular:

- Suitability for preloading of the assemblies (via hydraulic tensioning),
- Fatigue behaviour of the bolts on the bolt thread.

Concerning product packaging, transport, storage, maintenance, replacement and repair it is the responsibility of the manufacturer to undertake the appropriate measures and to advise his clients on the transport, storage, maintenance, replacement and repair of the product as he considers necessary.

It is assumed that the product will be installed according to the manufacturer's instructions or (in absence of such instructions) according to the usual practice of the building professionals.

Relevant manufacturer's stipulations, e.g., with regard to the intended end use conditions, having influence on the performance of the product covered by this European Assessment Document shall be considered for the determination of the performance and detailed in the ETA as long as the details of the assessment methods as laid down in this EAD are respected.

1.2 Information on the intended use(s) of the construction product

1.2.1 Intended use(s)

The high-strength structural bolting assemblies are intended to be used for metal constructions where a precise assembly preload is required. The high-strength structural bolting assembly and the corresponding bolting application are subject to tension or shear forces or both.

The high-strength structural bolting assemblies, when tightened hydraulically friction-less and torsion-free, provide an assembly precisely preloaded in the bolted connection with the required minimum preload in accordance with the relevant standards (for instance 70 % of ultimate tensile strength f_{ub} stress cross section A_s in accordance with EN 1993-1-8).

The design of the high-strength structural bolting assemblies is based on the class 10.9 for bolts as given in EN ISO 898-1, clause 5, and the class 10 for nuts as given in EN ISO 898-2, clause 5.2.1; however, within this EAD none of the given limit values apply, since these have to be the result of the testing described in clause 2.2.

1.2.2 Working life/Durability

The assessment methods included or referred to in this EAD have been written based on the manufacturer's request to take into account a working life of the high-strength structural bolting assemblies for the intended use of 50 years when installed in the works (provided that the high-strength structural bolting assembly is subject to appropriate installation (see 1.1)) These provisions are based upon the current state of the art and the available knowledge and experience.

When assessing the product, the intended use as foreseen by the manufacturer shall be taken into account. The real working life may be, in normal use conditions, considerably longer without major degradation affecting the basic requirements for works².

The indications given as to the working life of the construction product cannot be interpreted as a guarantee neither given by the product manufacturer or his representative nor by EOTA when drafting this EAD nor by the Technical Assessment Body issuing an ETA based on this EAD, but are regarded only as a means for expressing the expected economically reasonable working life of the product.

² The real working life of a product incorporated in a specific works depends on the environmental conditions to which that works is subject, as well as on the particular conditions of the design, execution, use and maintenance of that works. Therefore, it cannot be excluded that in certain cases the real working life of the product may also be shorter than referred to above.

2 ESSENTIAL CHARACTERISTICS AND RELEVANT ASSESSMENT METHODS AND CRITERIA

2.1 Essential characteristics of the product

Table 2.1.1 shows how the performance of high-strength structural bolting assemblies is assessed in relation to the essential characteristics.

Table 2.1.1 Essential characteristics of the product and methods and criteria for assessing the performance of the product in relation to those essential characteristics

No	Essential characteristic	Assessment method	Type of expression of product performance
Basic Works Requirement 1: Mechanical resistance and stability			
1	Yield strength $R_{p0,2}$ (stress at 0,2 % non-proportional elongation) and ultimate tensile strength R_m	2.2.1	level
2	Characteristic tension resistance of the nuts	2.2.2	level
3	Proof of hardness of bolts and nuts	2.2.3	level
4	Suitability for preloading of the assemblies	2.2.4	level
5	Fatigue behaviour of the bolts on the bolt thread	2.2.5	level
Basic Works Requirement 2: Safety in case of fire			
6	Reaction to fire	2.2.6	class

2.2 Methods and criteria for assessing the performance of the product in relation to essential characteristics of the product

This chapter is intended to provide instructions for TABs. Therefore, the use of wordings such as “shall be stated in the ETA” or “it has to be given in the ETA” shall be understood only as such instructions for TABs on how results of assessments shall be presented in the ETA. Such wordings do not impose any obligations for the manufacturer, and the TAB shall not carry out the assessment of the performance in relation to a given essential characteristic when the manufacturer does not wish to declare this performance in the Declaration of Performance.

2.2.1 Yield strength $R_{p0,2}$ (stress at 0,2 % non-proportional elongation) and ultimate tensile strength R_m

Purpose of the assessment

The aim of the test is the assessment of the yield strength and ultimate tensile strength of the stretch bolts and the stud bolts.

Assessment method

The yield strength and ultimate tensile strength of the stretch bolts and the stud bolts shall be determined by tests in accordance with EN ISO 898-1, clause 9.7. The minimum number of tests shall be 5 for all different nominal diameters which the ETA is intended to cover per each property class or property designation, per each type of coating and per each type and source of material.

Expression of results

The minimum values achieved for the yield strength $R_{p0,2}$ and the ultimate tensile strength R_m shall be stated in the ETA.

2.2.2 Characteristic tension resistance of the nuts

Purpose of the assessment

The aim of the test is the assessment of the characteristic tension resistance of the nuts.

Assessment method

The tension resistance of the round nuts shall be determined according to EN ISO 898-2, clauses 10.1.1 to 10.1.5. The minimum number of tests shall be 5. The maximum recorded force shall be determined for each test. In contrast to EN ISO 898-2, clause 10.1.6, no limit values for the force or acceptance criteria are defined. The maximum load for the nuts shall be determined within this test.

Expression of results

With the results of the 5 tests, a characteristic value shall be calculated in accordance with EN 1990, Annex D.7. The evaluation shall be statistical with the determination of 5 % fractile and a confidence level of 75 %.

2.2.3 Proof of hardness of bolts and nuts

Purpose of the assessment

The aim of the test is the assessment of the Vickers hardness of the bolts and of the nuts.

Assessment method

The hardness of bolts shall be determined in accordance with EN ISO 898-1, clause 9.9, in connection with EN ISO 6507-1 as surface hardness. The minimum number of tests shall be 5 for all 4 different nominal diameters which the ETA is intended to cover per each property class or property designation, per each type of coating and per each type and source of material.

The mechanical property of nuts as hardness shall be determined in accordance with EN ISO 898-2, clause 10.2.4 a), in connection with EN ISO 6507-1 as surface hardness. The minimum number of tests shall be 5 for all 4 different nominal diameters which the ETA is intended to cover per each property class or property designation, per each type of coating and per each type and source of material.

Expression of results

The minimum values achieved for the Vickers hardness for the bolts and for the nuts shall be stated in the ETA.

2.2.4 Suitability for preloading of the assemblies

Purpose of the assessment

The aim of the test is the assessment of the suitability for preloading of the high-strength structural bolting assemblies.

Assessment method

At least 5 preload tests shall be carried out for each thread size and for each of both configurations in accordance with Appendix B which are intended to be covered by the ETA. The clamping length ratio shall at least be $k/d = 2.5$.

Default values for clamping lengths and plate thicknesses (see Annex B) are given in Table 2.2.4.1. The standard test plates shall be made of steel S355 in accordance with EN 10025-2, with a thickness tolerance of -0,0% to +2,0%. The integrated washers are considered part of the clamping length and shall be included in the total. In case the manufacturer wishes to have another configuration be assessed additionally, such deviating test setup shall also be used. In any case, the test setup(s) shall be given in the ETA together with the indication of the related product performance.

Table 2.2.4.1 Default clamping lengths and plate thicknesses for the preload test for $k/d = 2,5$

Thread size	nominal diameter d [mm]	clamping length k [mm]	thickness plate 1 l_1 [mm]	thickness plate 2 l_2 [mm]
M20	20	50	25	25
M22	22	55	27,5	27,5
M24	24	60	30	30
M27	27	67,5	33,75	33,75
M30	30	75	37,5	37,5
M36	36	90	45	45
M39	39	97,5	48,75	48,75
M42	42	105	52,5	52,5

M45	45	112,5	56,25	56,25
M48	48	120	60	60
M52	52	130	65	65
M56	56	140	70	70
M60	60	150	75	75
M64	64	160	80	80
M72	72	180	90	90
M80	80	200	100	100
M90	90	225	112,5	112,5
M100	100	250	125	125

The preload for the assessment shall be generated hydraulically by axial elongation of the bolt by means of a bolt tensioning cylinder, which is installed onto the thread projection on the preload application side. An example of a bolt tensioning cylinder and the process steps for tensioning the round nut are shown in Annex C.

The preload F_{VM} before pressure release, the torque of the nut M_{VM} , the remaining preload $F_{p,C}$ and the preload curve shall be recorded. The values for F_{VM} and M_{VM} are chosen depending on the type of hydraulic bolt tensioner used for the test. The test procedure is within the elastic range of the bolt. The bolt load $F_{0,2}$ at the 0,2% yield point shall not be exceeded ($F_{0,2} = R_{p0,2} \cdot A_S$). If $F_{0,2}$ has been exceeded, the test shall be repeated with reduced initial preload F_{VM} . For $R_{p0,2}$ the minimum value from clause 2.2.1 of this EAD shall be used.

$R_{p0,2}$ 0,2%-proof strength
 A_S stress cross-section

Expression of results

The remaining preload $F_{p,C}$ and the required preload F_{VM} before pressure release shall be evaluated statistically (determination of 5 % fractile, confidence level 75 %) and given in the ETA. Generally, a normal distribution can be assumed.

2.2.5 Fatigue behaviour of the bolts on the bolt thread

Purpose of the assessment

The purpose of the assessment is to verify the detail category 63 or 71 ($\Delta\sigma_C$) in accordance with EN 1993-1-9, clause 8, table 8.1, of bolting assemblies subjected to nominal stress.

Assessment method

Fatigue tests shall be carried out in accordance with ISO 3800, clause 6. The bolts shall be tested free of preload and torsion. The number of fatigue tests shall be at least $n = 12$, with tests being carried out on three stress ranges ($\Delta\sigma_i$). The smallest and largest bolt dimensions shall be tested on fatigue for one and the same surface condition. In addition, three intermediate sizes with the same number of tests shall be tested. If it is not possible to test the largest dimension, the applicability of the size influence factor k_s according to EN 1993-1-9 shall be confirmed based on at least five series of tests with $n = 12$ specimens each. In accordance with EN 1993-1-9, clause 10, table 10.2, $k_s = (30/d)^{0.1}$ applies to hot-dip galvanized bolting assemblies for diameters greater than 30 mm and $k_s = (30/d)^{0.25}$ for all other surface layer conditions.

The fatigue tests shall be carried out at constant amplitude loading (CAL) with constant mean stress. The mean load level is linked to the bolt preload $F_{p,C}$ in the operating state. The respective values for $F_{p,C}$ are determined by testing in accordance with clause 2.2.4. The stress levels $\Delta\sigma$ shall be selected in such a way that fractures occur in the finite life region of the S-N curve. The test loads shall be calculated considering the stress cross section A_S for the bolt. The test results (fracture between $10^4 \leq N \leq 5 \cdot 10^6$ load cycles) shall

statistically be evaluated in accordance with Annex D.1 of this EAD. In addition, three further bolts shall be tested until the limit number of load cycles $N = 5 \cdot 10^6$ has been reached without failure (= run out).

The above-mentioned test shall be carried out separately for each type of surface protection and thread production process, since these production methods may significantly influence the test results. The type of thread production and the surface protection shall be stated in the ETA.

Evaluation of the fatigue test results

For the evaluation a detail category $\Delta\sigma_C$ in accordance with EN 1993-1-9, clause 7.1, in the nominal stress range, shall be determined. The detail category is defined in EN 1993-1-9, clause 1.3.3.2, as a curve-based indication for fatigue assessment of a particular detail with a given stress fluctuation. The detail category shall be evaluated statistically based on EN 1990, Annex D.7.

The evaluation shall be based on the following assumptions:

- Test specimens without fracture at $N > 5 \cdot 10^6$ load cycles are classified as run-out and are not considered in the statistical evaluation.
- The statistical evaluation shall be carried out for a variable and a given constant slope of the fatigue strength curve of $m = 3$.
- Failure is defined as the fracture of the bolt. The nominal cross section is defined as the stress cross section for ISO metric bolts. Failure in the thread run-out or under the bolt head is not permitted. Such test results shall not be taken into account for statistical evaluation.

Expression of results

The detail category $\Delta\sigma_C$ in accordance with EN 1993-1-9, clause 7.1, considering the nominal stress range, shall be stated in the ETA.

2.2.6 Reaction to fire

The high-strength structural bolting assemblies are considered to satisfy the requirements of class A1 of the reaction-to-fire performance in accordance with the Commission Decision 96/603/EC, as amended by Commission Decisions 2000/605/EC and 2003/424/EC, without the need for testing on the basis of it fulfilling the conditions set out in that Decision and its intended use being covered by that Decision.

Therefore, when the conditions referred to are fulfilled, the performance of the product is class A1 which shall be given in the ETA.

3 ASSESSMENT AND VERIFICATION OF CONSTANCY OF PERFORMANCE

3.1 System(s) of assessment and verification of constancy of performance to be applied

For the products covered by this EAD the applicable European legal act is Commission Decision 98/214/EC, as amended by 2001/596/EC.

The system to be applied is **2+**.

3.2 Tasks of the manufacturer

The cornerstones of the actions to be undertaken by the manufacturer of the product in the procedure of assessment and verification of constancy of performance are laid down in Table 3.2.1.

Table 3.2.1 Control plan for the manufacturer; cornerstones

No	Subject/type of control	Test or control method	Criteria, if any	Minimum number of samples	Minimum frequency of control
Factory production control (FPC) [including testing of samples taken at the factory in accordance with a prescribed test plan]					
1	Dimensions and tolerances	Measuring	According to control plan	According to control plan	Every production unit
2	Mechanical properties of stretch bolts and stud-bolts (yield strength, ultimate tensile strength, hardness)	Test in accordance with EN ISO 898-1			
3	Mechanical properties of round nuts (proof load, hardness)	Test in accordance with EN ISO 898-2			
4	Check of initial materials	Inspection document 3.1 in accordance with EN 10204 (to be furnished by the supplier)	Comparison with manufacturer's specifications		
5	Surface treatment (galvanising, zinc plating)	Thickness measurement	Comparison with manufacturer's specifications		

3.3 Tasks of the notified body

The cornerstones of the actions to be undertaken by the notified body in the procedure of assessment and verification of constancy of performance for the high-strength structural bolting assemblies are laid down in Table 3.3.1.

Table 3.3.1 Control plan for the notified body; cornerstones

No	Subject/type of control	Test or control method	Criteria, if any	Minimum number of samples	Minimum frequency of control
Initial inspection of the manufacturing plant and of factory production control					
1	Ascertain that the factory production control with the staff and equipment are suitable to ensure a continuous and orderly manufacturing of the high-strength structural bolting assembly	Verification of the complete FPC, to be implemented by the manufacturer	Laid down in control plan	-	When starting the production or a new production line
Continuous surveillance, assessment and evaluation of factory production control					
2	Ascertain that the system of factory production control and the specified automated manufacturing process are maintained taking account of the control plan	Verification of the controls carried out by the manufacturer on the raw materials, on the process and on the product as indicated in Table 3.2.1	Laid down in control plan	-	Once per year

4 REFERENCE DOCUMENTS

EN 1990:2023	Eurocode - Basis of structural and geotechnical design
EN 1993-1-8:2024	Eurocode 3 - Design of steel structures - Part 1-8: Joints
EN 1993-1-9:2025	Eurocode 3: Design of steel structures - Part 1-9: Fatigue
EN 10025-2:2019	Hot rolled products of structural steels - Part 2: Technical delivery conditions for non-alloy structural steels
EN 10204:2004	Metallic products – Types of inspection documents
EN 14399-1:2015	High-strength structural bolting assemblies for preloading - Part 1: General requirements
EN 14399-2:2015	High-strength structural bolting assemblies for preloading - Part 2: Suitability for preloading
EN 14399-3:2015	High-strength structural bolting assemblies for preloading - Part 3: System HR - Hexagon bolt and nut assemblies
EN 14399-4:2015	High-strength structural bolting assemblies for preloading - Part 4: System HV - Hexagon bolt and nut assemblies
EN 14399-5:2015	High-strength structural bolting assemblies for preloading - Part 5: Plain washers
EN 14399-6:2015	High-strength structural bolting assemblies for preloading - Part 6: Plain chamfered washers
EN 14399-7:2018	High-strength structural bolting assemblies for preloading - Part 7: System HR - Countersunk head bolt and nut assemblies
EN 14399-8:2018	High-strength structural bolting assemblies for preloading - Part 8: System HV - Hexagon fit bolt and nut assemblies
EN 14399-9:2018	High-strength structural bolting assemblies for preloading - Part 9: System HR or HV - Direct tension indicators for bolt and nut assemblies
EN 14399-10:2018	High-strength structural bolting assemblies for preloading - Part 10: System HRC - Bolt and nut assemblies with calibrated preload
EN ISO 898-1:2013+AC:2013	Mechanical properties of fasteners made of carbon steel and alloy steel - Part 1: Bolts, screws and studs with specified property classes - Coarse thread and fine pitch thread (ISO 898-1:2013+Cor 1:2013)
EN ISO 898-2:2022	Fasteners - Mechanical properties of fasteners made of carbon steel and alloy steel - Part 2: Nuts with specified property classes (ISO 898-2:2022)
EN ISO 6507-1:2023	Metallic materials - Vickers hardness test - Part 1: Test method (ISO 6507-1:2023)
EN ISO 6892-1:2019	Metallic materials - Tensile testing - Part 1: Method of test at room temperature (ISO 6892-1:2019)
ISO 3800:1993	Threaded fasteners – Axial load fatigue testing – Test methods and evaluation of results

ANNEX A

ANNEX A: EXAMPLE FOR HIGH-STRENGTH STRUCTURAL BOLTING ASSEMBLIES AND APPLICATION TOWER FLANGE

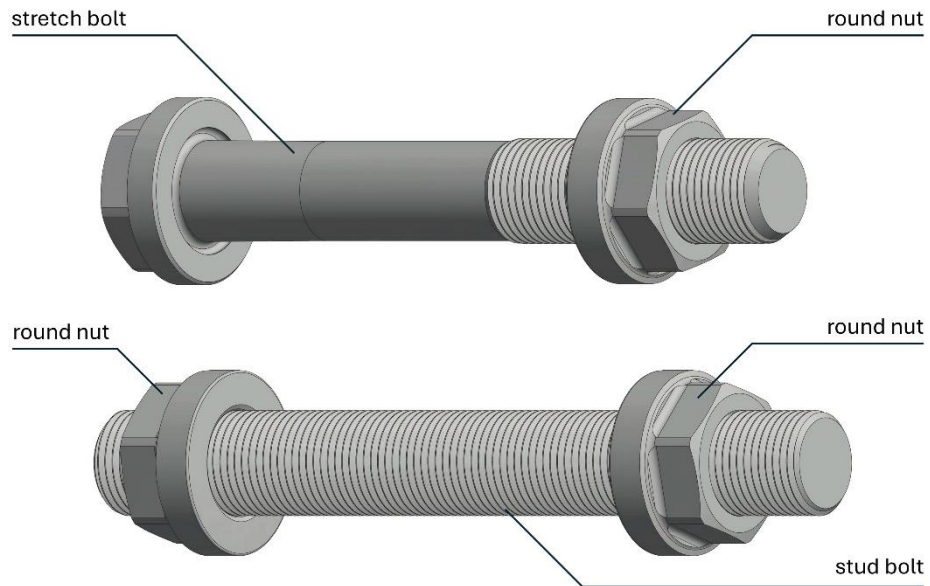


Figure A.1: Example of high-strength structural bolting assemblies

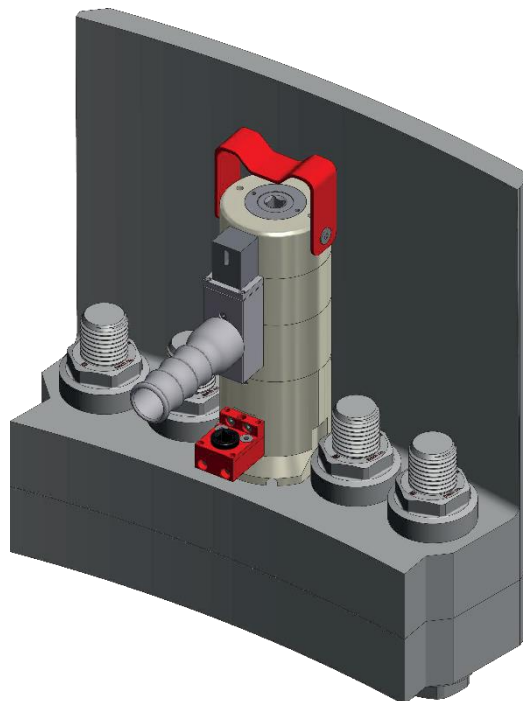
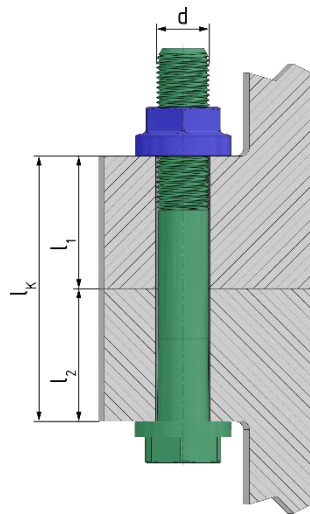


Figure A.2: Application example for a bolted connection in wind turbine towers

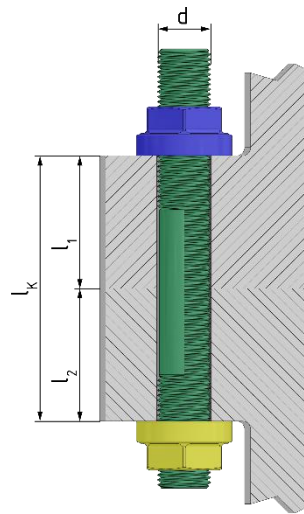
ANNEX B

ANNEX B: DIFFERENT POSSIBLE COMBINATIONS OF STRETCH BOLT, STUD BOLT WITH ROUND NUTS IN A BOLTED CONNECTION OF A TOWER FOR A WIND TURBINE

Execution with stretch bolts
 - 1x round nut
 - 1x stretch bolt



Execution with stud bolts
 - 2x round nut
 - 1x stud bolt



Legend

Colour:

Blue: Round nut installed on the preload application side

Green: Stud / stretch bolt

Yellow: Round nut installed on the opposing side

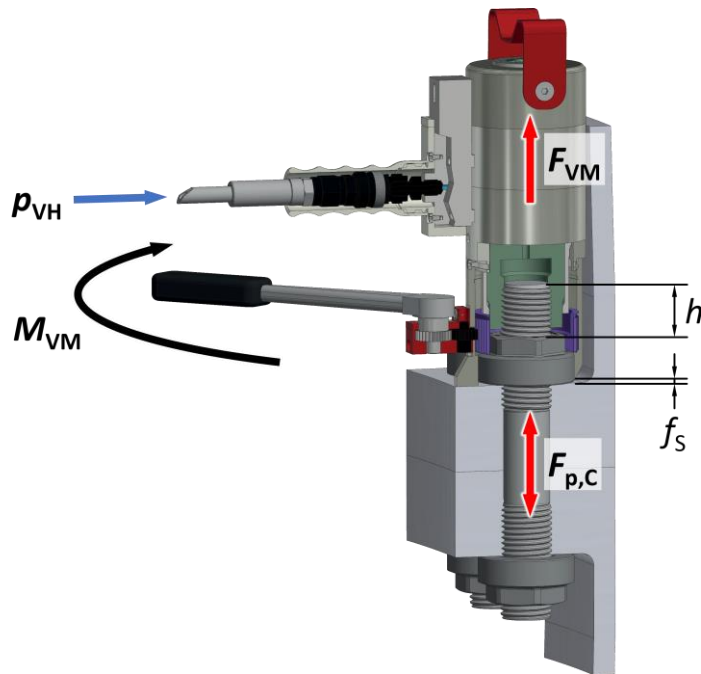
Symbols:

d Nominal diameter
 l_k Clamping length

l_1 plate thickness plate 1
 l_2 plate thickness plate 2

ANNEX C

ANNEX C: SAMPLE OF A BOLT TENSIONING CYLINDER FOR TENSIONING THE BOLTED CONNECTION WITH THE HYDRAULIC FRICTIONLESS AND TORSION-FREE TIGHTENING



Process steps:

1. The bolt tensioning cylinder is installed onto the thread projection h ($h = 1 \cdot d$) on the preload application side.
2. The generation of the hydraulic pressure p_{VH} causes a purely axial elongation f_s of the bolt. The nut, which is not under load, moves away from the surface.
3. Afterwards the nut is torque-controlled tightened with the torque M_{VM} . The initial preload F_{VM} is generated.
4. Then, the bolt is released of the hydraulic pressure p_{VH} and the applied initial preload F_{VM} is transferred to the target preload $F_{p,C}$ in the bolted connection.

ANNEX D

ANNEX D: STATISTICAL EVALUATION OF FATIGUE TEST RESULTS**D.1 Statistical evaluation of fatigue test results****D.1.1 Linear regression analysis**

Assuming that $\log N = a + b \log S$

setting $y = \log N$

and $x = \log S$

Therefore $y = a + b x$.

According to the upper equations the evaluation of the coefficient of the linear regression curve is given by

$$b = \frac{n \cdot \Sigma(x_i y_i) - \Sigma x_i \cdot \Sigma y_i}{n \cdot \Sigma x_i^2 - (\Sigma x_i)^2}$$

$$a = \frac{1}{n} \cdot (\Sigma y_i - b \cdot \Sigma x_i)$$

For $N_c = 2 \cdot 10^6$ cycles:

$$\log S_c = \frac{\log N_c - \log a}{b}$$

D.1.2 Determination of the characteristic strength at 2 10⁶ cycles

The characteristic fatigue strength curve shall be determined at a fractile α of 5 %; this implies that 95 % of the test results fall within the safe domain delimited by the lower straight line confidence limit.

From the calculation table, we have

$$S_{xx} = \Sigma x_i^2 - \frac{(\Sigma x_i)^2}{n}$$

$$S_{yy} = \Sigma y_i^2 - \frac{(\Sigma y_i)^2}{n}$$

$$S_{xy} = \Sigma x_i y_i - \frac{\Sigma x_i \cdot \Sigma y_i}{n}$$

and, for the evaluation of the variance

$$s^2 = \frac{S_{yy} - b \cdot S_{xy}}{n - 2}$$

$$f = 1 + \frac{1}{n} + \frac{(x_c - \bar{x})^2}{S_{xx}} \quad \text{with } x_c = \log S_c \quad \text{and } \bar{x} = \frac{\Sigma \log S_i}{n}$$

Therefore, the regression line equation is given by

$$\log N = (\log a - t(0,95) s \sqrt{f}) + b \log S$$

with

$t(0,95)$ = the students t-distribution value for $(n-2)$.

The characteristic value of the stress range at $2 \cdot 10^6$ cycles for the 95% confidence limit shall be obtained from

$$\log S_c \geq \frac{\log N_c - (\log a - t(0,95) s \sqrt{f})}{b}$$

D.1.3 Linear regression analysis for a constant slope b

For every fatigue test (N_i and S_i) a $(\log a)_i = \log N_i + b \log S_i$ shall be calculated. Normally the slope b is negative so in the above equation the algebraic sign of b is inverted. Additionally, for every test $[\log \bar{a} - (\log a)_i]^2$ the 95% confidence limit shall be evaluated.

Thus, the mean of all $(\log a)_i$ results to $\log \bar{a} = \frac{\sum(\log N_i + b \log S_i)}{n}$, with n = number of the tests between 10^4 and $5 \cdot 10^6$ cycles.

This mean value of $\log \bar{a}$ in relation to the characteristic lifetime ($N_c=2 \cdot 10^6$) results in the characteristic value of the stress range $S_c = \left(\frac{10^{\log \bar{a}}}{2 \cdot 10^6}\right)^{\frac{1}{b}}$

The standard deviation shall be obtained from $s = \sqrt{\frac{\sum(\log \bar{a} - (\log a)_i)^2}{n-1}}$

With the Student's t distribution, the 95% confidence interval of $\log \bar{a}$ results to $\log \bar{a}_{95\%} = \log \bar{a} - t s$. The characteristic value of the stress range shall be obtained from $S_{C,95\%} = \left(\frac{10^{\log \bar{a}_{95\%}}}{2 \cdot 10^6}\right)^{\frac{1}{b}}$.